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STUDIES ON THE SOYBEAN CYST NEMATODE, HETERODERA GLYCINES AND ITS INJURY TO SOYBEAN PLANTS IN JAPAN

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THE PLANT DISEASE REPORTER

MYCOLOGY AND PLANT DISEASE REPORTING SECTION

Crops Protection Research Branch Plant Industry Station, Beltsville, Maryland

STUDIES ON THE SOYBEAN CYST NEMATODE HETERODERA GLYCINES AND ITS INJURY TO SOYBEAN PLANTS IN JAPAN

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Minoru Ichinohe[1]

1. HISTORICAL REVIEW

The occurrence of the soybean-cyst nematode in Japan was first recorded by S. Hori in 1915. According to his report, Hori discovered the nematode on the roots of a soybean plant which was sent from Shirakawa, Fukushima Prefecture, where the same disease had been observed for many years. He noticed that this nematode was different from the root-knot nematode which had been well known in Japan at that time, and asked S. Uchida to identify it. In accordance with S. Uchida's identification, Hori referred the nematode to a species closely related to Heterodera schachtii which had been known as the causal nematode of "sugar-beet sickness" in Europe. Hori added in his paper that it is necessary to compare this nematode with Heterodera göttingiana which attacks pea in Germany.

In the next year, T. Ishikawa (1916) reported that in Niigata Prefecture there had occurred for many years the soybean disease which was called "Tsukiyobyo" (literally translated into "moon night disease") probably after the characteristic appearance of the diseased part of the fields which was likened to full moon, and reported that at Omote-ga-hara, Uonuma-gun, Niigata Prefecture the land became incapable of cropping soybeans due to this disease. He mentioned in his paper that the causal organism was thought to be the same which Hori (1915) reported.

K. Katsufuji (1919) and S. Ito (1921) reported the occurrence of this nematode in Hokkaido, the northernmost island of Japan. According to Ito (1921), this disease had been observed on soybean in Iburi and Oshima Provinces, southern part of Hokkaido, for more than 10 years, and the nematode was thought to be the same species as the sugar-beet nematode, Heterodera schachtii, judging from the morphology of females and larvae. In his paper, Ito named this disease "Daizu-iwo-byo" (literally translated into "soybean yellow dwarf disease") after the characteristic symptom of yellowish discoloration of the diseased plant.

T. Tanaka (1921) reported the occurrence of soybean "moon night disease" in Ibaragi Prefecture and thought that the causal nematode was different from both root-knot nematode (Heterodera marioni) and sugar-beet nematode (Heterodera schachtii).

K. Fujita and O. Miura (1934) studied the host range of this nematode and revealed that it can infect the soybean, azuki bean, kidney bean, and multiflora bean, but did not attack the other legumes tested. These are: Pea, Pisum sativum; lima bean, Phaseolus limensis; broad bean, Vicia faba; common vetch, V. sativa; peanut, Arachis hypogea; cowpea, Vigna sinensis; red clover, Trifolium pratense; Lupinus albus; Lathyrus tingitanus. The following plants were also tested without infection: Chenopodiaceae (sugar beet, Beta vulgaris; spinach, Spinacia oleracea), Solanaceae (potato, Solanum tuberosum), Cruciferae (cabbage, Brassica oleracea var. capitata; pe-tsai, B. pekinensis; kohlrabi, B. oleracea var. caulorapa; rape, B. napus), and Gramineae (oats, Avena sativa; barley, Hordeum vulgare; wheat, Triticum aestivum; corn, Zea mays). These results indicated that the soybean-cyst nematode was a biological race of H. schachtii occurring in Japan, similar to those which were called the pea-, oat-, and potato-races of Heterodera schachtii in Europe.

Franklin (1940) raised some so-called biological strains (or races) of H. schachtii to the rank of a species after morphological studies of those nematodes. Since then, the specific status of soybean-cyst nematode has been so indistinct that although most of the workers have referred to it as H. schachtii, some workers (Filipjev and Schuurmans Stekhoven-1941, Goffart-1951, Yokoo-1951) have considered it to be H. göttingiana.

Ichinohe (1952) compared the soybean-cyst nematode with specimens of other species of Heterodera, and described it under the name Heterodera glycines. The main differences be-

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tween H. glycines and H. schachtii are in punctation of cyst wall, presence of the "yellow phase" of the living female, ratio of length to breadth of cyst, and length of stylet in the male. H. glycines differs from H. göttingiana in that the spicules of the former species have bifid tips while H. göttingiana has spicules with trifid tips. In addition, the mature cyst of H. glycines has "brown knobs" at the posterior end which are lacking in H. göttingiana.

2. DISTRIBUTION IN ASIA

The soybean-cyst nematode has been found in many places in Japan (Hokkaido-, Honshu-, Shikoku-, Kyushu Islands), but there are few reports on distribution from these islands except Hokkaido. In Hokkaido, the soybean-cyst nematode was discovered in four localities (Date-, Sobetsu-, Abuta-, Horobetsu-mura) in or about 1920. The survey made in 1932 to 1935 by the Hokkaido Agricultural Experiment Station revealed 49 localities infested by this nematode. As of 1958 more than 64 localities were found to be infested. It can be said that all of these infested localities are restricted to the southern part of Hokkaido, particularly to such types of soil as sandy, less-organic, and volcanic ash soil.

It is reported by T. Yokoo (1936) that this nematode has been observed in Korea.

K. Nakata and H. Asuyama (1938) reported that the soybean-cyst nematode was found in Manchuria (present Red China's territory). (The details of this report from Manchuria are noted in section 10, page 247.

No report on the occurrence of this nematode has been made from any other place in Asia.

3. THE MORPHOLOGY OF THE SOYBEAN-CYST NEMATODE

Morphology of the adult male is as follows: Body is 1.2 - 1.4 mm (M = 1.33 mm) in length and 27 - 31 μ (M = 28.6 μ) in width. Cuticle is 3.0 - 3.5 μ in thickness and consists of three layers. The transverse striations on the cuticle are 1.5 - 2.4 μ apart, although this varies dependent upon the portion of body. The lateral field is marked by four longitudinal incisures, beginning as three incisures anteriorly and increasing to four just posterior to the base of spear, extending the length of the body and around the blunt tail posteriorly. The head region is hemispherical, 6.2 x 11.3 μ in size, and bears four or five annules. In face view the head region has six radially arranged lips, of which the lateral lips, possessing slit-like openings of amphid aperture, are smaller in size than the submedian lips. The cephalic framework is heavily sclerotized. The spear is 26.1 μ in mean length with laterally to anteriorly protruded knobs. The oesophagus, 160 - 180 μ (M = 173 μ) long, is divided into three parts. The median bulb is 19.4 μ x 12.8 μ in size, and from the anterior end of the body to the posterior side of the median bulb is 90 - 100 μ (M = 94.6 μ). The orifice of the dorsal oesophageal gland is located about 4 μ posterior to the spear. The testis starts at the middle of the body or slightly anterior. The spicules are slightly arcuate and 34 μ long with bifid tips. The gubernaculum is 11.5 - 12.0 μ (M = 11.7 μ) in length. The excretory pore is located ventrally 144 $\pm$ 11.0 μ from the anterior. The phasmid is 2 to 8 μ (usually 4 to 6 μ) from the posterior. Tail is 1.7 - 5.5 μ (M = 3.5 μ) in length. Table 1 compares males of this and three other species.

Morphology of the adult female is as follows: The body is lemon-shaped with a short neck, 0.07 - 0.10 mm long, anteriorly and with a prominent vulva posteriorly. It varies from 0.47 to 0.79 mm in length and 0.21 to 0.58 mm in width. The color is white at first and then turns yellow as eggs develop, -- the "yellow phase" as described by Jones (1950) for H. rostochiensis and H. galeopsidis. The newly developed female is coated with a so-called subcrystalline layer which persists on the brown cyst. The cuticle is thickened, being from 7 - 9 μ at the middle part of the body to 9 - 11 μ at the neck and at the posterior region. The cuticle consists of three layers. The outer layer is marked by a rugose pattern except for several annulations on the anterior end. In face view the head region bears no six-radial lips, but a hexagonal circumoral cuticular plate. The spear is somewhat slender with posteriorly protruded knobs and is 27.5 μ in mean length. The oesophagus and median bulb are much larger than those of the male and larvae, being 39.0 x 32.5 μ in size. The anus is located ventrally 75 to 90 μ from the middle of the vulva. The paired ovaries fill almost the entire body cavity and open to the posteriorly located vulva. A gelatinous egg sac roughly one-third of body in size is attached to the vulva and may contain as many as 200 eggs. Various sclerotized structures surround the vulva.

The cyst is brown and lemon-shaped. It is 0.56 - 0.85 mm (M = 699 $\pm$ 60 μ) in length, 0.35 - 0.59 mm (M = 490 $\pm$ 54 μ) in width, and 1.43 in ratio of length to breadth (Table 2). The cyst wall consists of two layers, of which the outer layer is marked by a rugose pattern. The inner layer has minute punctations which are usually arranged with a tendency to run in parallel rows particularly on part of the posterior region.

Table 1. Comparisons of males of Heterodera[a].

Species	Body length (μ)	Spear length (μ)	Tip of spicules
H. schachtii (mangold)	1.468-0.0095	29.71-0.4104	Bifid
H. gottingiana (pea)	1.295-0.0188	27.54-0.4047	Trifid
H. rostochiensis (potato)	1.113-0.0089	27.39-0.4773	Monofid
H. glycines (soybean)	1.313-0.0980	26.80-0.26	Bifid

[a] From Franklin (1940) in part.

Table 2. Variations in the size of cyst of the soybean-cyst nematode.

No. of group of 10 cysts	Length			Width			Ratio av. length to av. width
	Max.	Min.	Av.	Max.	Min.	Av.	
1	808	640	726	589	438	523	1.39
2	850	614	698	547	387	475	1.47
3	791	614	695	564	370	494	1.41
4	800	623	705	555	429	503	1.40
5	757	606	687	572	387	473	1.45
6	774	589	683	547	404	460	1.48
7	808	572	709	547	370	478	1.48
8	808	555	711	581	354	513	1.39
9	741	600	675	572	421	482	1.40
10	808	564	708	581	404	492	1.44

The first-stage larvae complete their development within the egg, and cast off the first-stage larval cuticle when they hatch. The hatched larva (the second-stage larva) is 450 - 490 μ (M = 470.6 $\pm$ 17 μ) in length, which falls into the "medium" group when measured by the standard technique of Fenwick and Franklin (1951). The body width is 18.0 - 18.5 μ (M = 18.3 μ). The head region is 4.5 x 8.9 μ in size and bears three or four annules. In face view the head region bears six radially arranged lips. The cephalic framework is heavily sclerotized. The spear is 23.1 $\pm$ 0.2 μ long with anteriorly protruded knobs. The median bulb is 16.5 x 10 μ in size; the distance between the anterior and the end of the median bulb is 69 μ. The orifice of the dorsal oesophageal gland is about 4 μ posterior to the spear. The anus is located 42.0 to 47.0 μ (M = 45.0 μ) from the tail tip. The genital primordium is 15 x 8.5 μ in size. The body cavity extends to 20 μ posterior to the anus. The excretory pore is located ventrally 92 μ from the anterior. The phasmid is 10 μ, five or six annules, posterior to anus.

The eggs are 98 - 118 μ (M = 107.5 $\pm$ 4.8 μ) long and 40 - 47 μ (M = 42.7 $\pm$ 2.1 μ) wide.

4. SYMPTOMS CAUSED BY THE SOYBEAN-CYST NEMATODE

The "yellow dwarf" disease caused by the soybean-cyst nematode appears in fields toward the middle of July, about 2 months after sowing. It is characterized by severe retardation of growth, stunting, and yellowish appearance on the aerial parts of the plants.

The foliage of the diseased plant falls off early. The plant bears only a few flowers, and a few seeds which are smaller in size and inferior in quality to the normal ones.

The roots of affected plants bear many developed lateral rootlets and in most cases many fewer bacterial nodules than those of healthy plants.

In the field the disease occurs in more or less circular patches at first, and these patches spread as the season proceeds. If soybeans are successively planted on the infested land, these patches will cover the whole field within 2 or 3 years. Actually, due to these yellowish and sunken patches in the field, we can easily recognize the occurrence of disease from outside of the field, in many cases even from a distance.

It is not rare that a smaller yield than the seed sown has been harvested.

5. HOST PLANTS AND THE PARASITISM OF THE SOYBEAN-CYST NEMATODE

The hosts of the soybean-cyst nematode hitherto recorded by several authors show that the host plants are rather restricted in number. Fujita and Miura (1934) revealed that this nematode attacks the soybean with the most severity, the azuki bean always slightly, and only a trace of infection was found on the kidney bean and the Spanish runner bean (multiflora bean).

Ichinohe (1953) reported the nematode-infection indices of these four plants, based on the number of the white females attacking the tap roots of plants which were grown for 6 weeks in infested soil. These indices are:

Soybean (Glycine max)	28.3
Azuki bean (Phaseolus angularis)	26.7
Kidney bean (Phaseolus vulgaris)	3.2
Spanish runner bean (Ph. multiflorus)	0

It was noticed that these differences in the degree of nematode infection among the four susceptible plants were not related to the number of larvae that invaded the roots. The author also proved that the rates of larval development inside the different hosts were almost identical and that the exceedingly small number of the females on the kidney bean was probably due to the following circumstances: On the soybean and the azuki bean, the young adult females break the cortical tissue of the roots of the host plant as they develop, and finally they protrude from the roots. On the kidney bean, however, the young females in the root tissue were not fully grown and of small size, and very few females could break to the surface of the root. Egg production was also decreased. Though Fujita and Miura (1934) had reported the multiflora bean to be a host plant of this nematode, the author observed that the larvae which invaded the root could not complete their development and that none had reached the adult female stage. This fact convinced the author that this plant is not a host plant.

Glycine ussuriensis was proved to be a host of the soybean-cyst nematode by Ichinohe (1955). This plant shows typical symptoms in above-ground parts and seems similar to the soybean in susceptibility to this nematode. Glycine ussuriensis is said to be a wild-type of soybean, and grows naturally in Honshu.

We have never tested whether or not Vicia sativa and Lespedeza stipulacea, which were reported to be hosts of the soybean-cyst nematode in the United States of America, are host plants in Japan. These plants are not common in Hokkaido. The author found very recently that one species of Lespedeza which is a common annual weed in certain places in Honshu seems to be an undescribed host plant of this nematode.

The parasitism of the soybean-cyst nematode to 28 species of plants generally not regarded as host plants was tested. The plants were grown in 5-inch pots inoculated with many cysts of this nematode and examined every 7 days for the presence of invading larvae and, if larvae were found, on the amount of development undergone. The results of this test indicated that this nematode always invaded the roots of many species of leguminous plants other than the hitherto known host plants, but that plants not belonging to Leguminosae showed almost no evidence of an invasion. Moreover, in certain species such as peas, broad beans etc., many larvae invaded but failed to develop after invasion, and in other species such as alsike clover, lima bean, etc., occasionally the partly-grown parasite, not reaching to the adult stage, could be found. The fact that the soybean-cyst nematode invades the roots of plants hitherto not regarded as host plants is of considerable importance, because those plants may be applied as a "trap crop" to control this pest.

The hatching responses of larvae when they were exposed to the root diffusates of host plants or non-host plants were investigated during winter months of 1949-1950, with negative results.

The root of the soybean responds to invasion by the nematode by the production of giant cells.

6. DEVELOPMENT OF THE SOYBEAN-CYST NEMATODE AND ITS POSSIBLE GENERATIONS IN ONE YEAR IN HOKKAIDO, JAPAN

The number of days necessary for the invading larva to mature in root tissue varies with environmental soil temeprature. The adult male appears earlier than the adult female. It is usually observed that a male lives in the gelatinous egg-sac of the female.

The number of eggs in a single cyst varied from 95 to 478, with an average of 262, when 66 cysts that had matured on soybean root were tested. The number of eggs found in the egg sac

varied from a few to 218. Single females produced from 228 to 564 eggs. Tokachi Province, Hokkaido, where this pest is most severe, is said to be extremely cold in winter. According to the meteorological report from Obihiro-shi, Tokachi, the land is frozen from November to April, with the maximum frozen depth of 27.4 cm on February 25[2]. This means that the cyst of the soybean-cyst nematode is highly resistant to cold. It was ascertained that cysts exposed to such a low temperature as -40° C for 7 months still contained viable eggs.

In 1952 and 1953, observations on the length of one generation of H. glycines were repeated eight times. One generation, from the time of larval entry at the time of germination of soybean seed to the time of appearance of embryonated eggs within the egg sac, takes 24 days at an average soil temperature of 23.3° and 41 days at 17.8° C. The rate of nematode development, which was expressed by a reciprocal of the number of days for one generation, was roughly proportional to the average soil temperature of each period. The author calculated the accumulated effective temperature needed for one generation of this nematode, to compute the possible number of generations per year in the Sapporo district, Hokkaido. The threshold temperature of nematode development was 10° C, thus the accumulated effective temperature necessary to complete one generation varied from 304 to 320, with an average of 313, day-degrees. In the Sapporo District, the time during which this nematode can develop was estimated as from June 1 to October 10, which coincides with the vegetative period of the host crop. Information about soil temperatures in the field was obtained from the Hokkaido National Agricultural Experiment Station. The total effective temperature of this period, calculated by summing up the temperatures in excess of the threshold temperature of development, was calculated as 1209 day-degrees at a depth of 5 cm in soil and 1069 day-degrees at a depth of 30 cm. The possible number of generations, dividing the total effective temperature by the accumulated effective temperature of 313 day-degrees was 3.8 at a depth of 5 cm and 3.4 at 30 cm. Thus, it is thought that a maximum of three generations would be completed on the soybean roots each year if conditions in addition to the soil temperatures were favorable.

7. DAMAGE OF SOYBEAN DUE TO THE SOYBEAN-CYST NEMATODE

Affected plants are decreased in height and yield; heavily infected plants may be only one-third as tall as normal plants. Seed production may be reduced to 10 to 30 percent of normal.

Table 3 shows the reduction of affected soybean plants studied in 1954 at Ebetsu, Hokkaido. In this field of about 2.5 acres, there occurred three patches of the diseased plants.

In August 1952, a survey of soybean-cyst nematode-injury was made in Memuro-machi, Tokachi Province, Hokkaido. Tokachi Province is supposed to be the biggest soybean-producing area in Japan, and is supposed to be the biggest soybean-producing area in Japan, and Memuro-machi is the town which has the widest soybean field in Tokachi Province. In this survey, every soybean field was inspected and damage due to nematode was graded into four classes: severe, moderate, slight, and none. We derived an average yield-reduction index D (41.3 percent) from the result of the survey by using the following formula:

$$D = \frac{\text{Total "severe" area} \times 3 + \text{Total "moderate" area} \times 2 + \text{Total "slight" area} \times 1}{\text{Total "injured" area} \times 3}$$

This index was applied to estimate the damage in the whole Tokachi Province as shown in Table 4.

The following study was made on October 4 to 6, 1949 in a soybean field belonging to the Tokachi Branch Station of the Hokkaido Prefectural Agricultural Experiment Station, Obihiro, Hokkaido. The affected "Tokachi-nagaha" variety of soybean totalling 127 plants taken from seven rows in this field were examined in respect to height, yield, and the number of new females attached on the root system. The plants varied 306 to 639 mm in height, 6 to 76 in number of pods, 0.7 to 28.3 grams in weight of seed, and 28 to 226 in number of new females per plant. The tested plants were divided into 12 gradations of damage according to the pod number per plant, and in each gradation an average and the standard deviation of the number of new females were calculated. These are shown in Table 5.

The data in Table 5 happened to show that fewer females were counted on the roots of heavily affected plants as well as on those of healthy plants than on roots of moderately affected plants.

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[2] Average 1922-1932.

Table 3. Growth of soybean plants taken from inside of three patches of diseased and healthy plants from outside of patches (average of 15 plants, September 20, 1954)

Patch of disease	Height of plant (cm)	Weight of plant (grams)	Number of pods per plant
" A "	22.9	4.0	2.4
" B "	34.2	15.6	6.2
" C "	41.5	20.0	10.7
Healthy	61.2	84.0	38.0

Table 4. Estimated loss due to soybean cyst nematodes in Tokachi Province.

Locality	Total cropping land (acres)	Total bean-cropping land (acres)	Percentage of bean-cropping	Total bean-cropping land where nema-disease was observed (acres)	Percentage of nema-diseased land to total bean cropping land	Average yield-reduction index (percent)	Amount of injury in millon yen
	A	B	$\frac{A}{B}$	C	$\frac{C}{B}$	D	C x D x E[a]
Memuro-machi	41639	17336	41.6	8707	50.2	41.3	115
Tokachi Province	326623	134102	41.1	37611	28.0	41.3	497

[a]E = Market price of soybean per Tan (or 1/4 acre) = 3520 (yen) x 2.46 (bales)

Table 5. Comparison between soybean plant growth and extent of infection by the soybean cyst nematode.

Number of group	Number of pods	Weight of seeds (grams)	Height of plant (mm)	Number of females	Number of plants
1	(8.1 ± 1.5)	1.2 ± 0.5	429.6 ± 34.7	52.8 ± 19.6	9
2	(13.4 ± 1.5)	3.3 ± 1.3	407.6 ± 57.4	66.1 ± 27.7	7
3	(18.4 ± 1.3)	3.8 ± 1.5	458.4 ± 52.8	79.5 ± 32.0	24
4	(22.7 ± 1.2)	4.5 ± 1.9	459.1 ± 44.4	93.8 ± 34.7	19
5	(28.2 ± 1.6)	6.5 ± 0.2	484.4 ± 72.9	86.8 ± 26.0	14
6	(33.6 ± 0.9)	7.3 ± 2.5	495.4 ± 35.5	140.3 ± 39.9	9
7	(38.6 ± 1.2)	10.4 ± 2.5	504.1 ± 48.3	135.0 ± 36.8	8
8	(41.9 ± 0.8)	11.1 ± 1.4	527.5 ± 60.5	142.0 ± 40.9	8
9	(47.2 ± 1.0)	12.8 ± 3.3	517.8 ± 39.3	166.0 ± 48.8	5
10	(52.6 ± 1.6)	13.5 ± 2.6	535.6 ± 42.2	165.2 ± 28.3	5
11	(56.5 ± 0.7)	16.5 ± 3.1	523.5 ± 30.0	101.8 ± 43.2	8
12	(66.9 ± 2.4)	20.1 ± 3.9	545.9 ± 32.3	118.1 ± 53.5	11

8. STUDIES ON CONTROL MEASURES

a. Control by the Cropping Method

It should be emphasized that rotation is still the only measure which is practicable and effective for control of the soybean-cyst nematode. According to our studies, it was shown that a 5- or 6-year rotation system (every fifth or sixth year cropping of soybean) seems to be almost perfect both for obtaining good yields of soybeans and for starving the nematodes, if we are careful to prevent introducing contaminated soil from other fields. In most cases, 3- or 4-year rotations were found unsatisfactory to control this nematode well, although comparatively high yields of soybean were obtained as compared with successive cropping. On the other hand, there are several cases in which even after more than 5 years of growing non-host plants, the yellowish dwarf patches appeared during the first year of soybeans. In such cases it is possible that the dispersal of the nematode cysts was made with agricultural implements, particularly when the plough was used carelessly. We think that in most cases the disease is spread in this way.

The most hopeful means of controlling this nematode is a rotation system which involves as many kinds of trap crops as possible. This work is now under way. According to the author's studies so far, several leguminous plants such as red clover, alfalfa, and peas seem to be useful for this purpose. The preliminary experiment showed a larger reduction of the nematode population by planting these crops than by fallowing or by planting host plants.

Also, we are testing the effectiveness of kidney bean, which is supposed to be a host of this nematode, as a trap crop. Our experiment showed that the plots where the kidney beans were planted had less population at the end of the growing season than the initial levels, though large increases of nematode populations occurred in adjacent plots where soybeans and azuki beans were grown. The reductions of population from the initial levels by one cropping of these crops were as follows:

Crop	Grown in	Percent reduction in population
Garden pea	Pot	86
Kidney bean	Frame	64
Kidney bean	Field	80
Fallow	Pot	62
Fallow	Frame	37
Fallow	Field	42

It must be true that control of this nematode by using these kinds of trap crops has actually been practiced to some extent by the farmer without his knowing it, since crops such as clover, alfalfa, and peas are fairly common in Hokkaido. Other crops which are common in Hokkaido are wheat, oats, barley, corn, potato, sugar beet, flax, and vegetables.

b. Chemical Control

The soybean cyst nematode is comparatively easy to control with moderate applications of standard nematocides such as D-D or EDB, but the complete eradication of this nematode is quite difficult or impossible. Also, it is true that the increase of the cyst population is so rapid that even if the chemicals reduced the population to a low level, a high population will again be built up by one or two croppings of soybean. Our experiments proved 75 pounds per Tan of D-D (which is equivalent to 300 pounds per acre) very effective for control. Seventy-five pounds per Tan of EDB (Nemafume W-20) was also effective, but this chemical seemed slightly less effective as compared with the same dosage of D-D. Several other chemicals such as N-869, 1,3-dichloropropene (Telon), DBCP (Fumazone), were also found to be effective.

Several factors make it difficult to use these chemicals for practical control. The most important is that every chemical costs more than 6,000 yen per Tan[3], which is uneconomical, and indeed impracticable. In Japan, soybeans are one of the cheapest crops. The reason that the farmers have been growing soybeans in Hokkaido so widely is that the soybean can be raised even in the comparatively sterile soil so long as it is free from nematodes. Also, soybeans are easy to raise, and the market price of soybean seeds seems rather stable. According to the agricultural statistics in Hokkaido in 1953, the average yield of soybean per Tan is 2.46

[3] 360 yen = 1 dollar; 4 Tan = 1 acre

bales (1 bale contains about 1.9 bushel) and the market price of 1 bale was 3,520 yen.

The other difficulty in the use of chemicals is that we have thus far no injecting instrument which can be used on a large scale in soybean fields.

c. Resistant Varieties

The highly resistant varieties of soybeans seem to be very few. Out of hundreds of varieties, we found so far four resistant varieties which had been used in a certain district of the northern part of Honshu where this nematode is also found. These varieties are: Daiichi-hienuki, Nangun-takedate, Geden-shirazu, and Tan-ryoku. All of these resistant varieties show healthy appearance and good yield in spite of having fairly large numbers of females on their roots. These varieties are so resistant that yields as high as about 80 percent of the uninfected plants of those varieties can be obtained, compared with 80 to 100 percent reduction of yield in susceptible varieties in the same field. The trouble is that all of these resistant varieties happen to be extremely late-ripening even in Honshu, and in most cases they fail to yield in Hokkaido. Also, it is true that the quality of seed of some resistant varieties is inferior. Of these 4 varieties, "Geden-shirazu" seems most hopeful both in its high resistance to soybean-cyst nematodes and the good quality of its seeds. Attempts are being made to shorten the growth period of this variety by M. Ishikawa in the Soybean Breeding Laboratory, Tohoku National Agricultural Experiment Station, Kariwano, Akita, Japan, and others.

9. STUDY ON THE NATURE OF VARIETAL RESISTANCE TO THE SOYBEAN-CYST NEMATODE

A study was made in 1955 to clarify the nature of varietal resistance, using the four varieties "Daiichi-hienuki" (resistant), "Nangun-takedate" (resistant), "Tokachi-nagaha" (susceptible), and "Kokuso" (susceptible).

When plants completed their growth in pots where the same levels of cysts were inoculated, infected plants of both resistant varieties showed 95 to 105 percent of the yield of healthy plants from non-infested pots, whereas noticeable disease symptoms and only 42 to 56 percent of the yield of healthy plants were recorded for both susceptible varieties.

The nature of the resistance seemed to be retained even when the resistant variety was grown under conditions that reduced the growth period by the short-day treatment. Under this treatment infected plants of both resistant varieties yielded 92 to 106 percent as much as non-infected healthy plants given the same treatment, whereas infected plants of the susceptible variety "Tokachi-nagaha" yielded only 68 percent as much as healthy plants.

A study on larval invasion of both resistant and susceptible varieties indicated that no general relationship exists between the number of the invading larvae and the degree of varietal resistance. Many larvae that invaded roots of the resistant plants, however, showed some signs of early death in all of those varieties. Both susceptible varieties had fewer dead larvae in their root tissue than the resistant varieties. The number of the dead larvae after invasion seems to increase with the degree of the varietal resistance.

The numbers of females per plant showed no differences between resistant and susceptible varieties, and the resistant varieties had more females than the susceptible varieties late in the season. But if the number females per unit weight of root is taken into consideration, it can be said that there were fewer females per gram of root on the resistant varieties than on the susceptible ones, because the resistant varieties had much bigger root systems.

The resistant varieties had very vigorous root systems with unusually large laterals.

The root nodules per unit weight of root were fewer on susceptible than on resistant varieties. Almost all plants grown in infested soil had fewer root nodules in comparison with those grown in sterilized soil. It was a variety with a comparatively large number of root nodules that had the smallest number of white females per unit weight of root.

Table 6 summarizes the results of these studies.

In all respects mentioned above, the resistant varieties tested are placed not in the "resistant" but in the "tolerant" classification, following Dropkin (1955), and it is thought that some ecological features of the resistant varieties are associated with their resistance. These are: 1) failure of any large number of larvae to survive after entering, 2) increase in the activity of root-nodule bacteria, 3) great growth of the root system and consequently of above-ground parts.

Table 6. A comparison of nematode infection, growth and nodulation of susceptible and resistant soybean varieties examined on August 7-8, 1955 (upper figure) and on September 6-9, 1955 (lower figure).

Variety	Number of females: Per plant	Number of females: Per gram of root	Weight of root (grams)	Number of lateral roots	Number of bacterial nodules: Per plant	Number of bacterial nodules: Per gram of root
Daiichi-	108	4.3	27.0	13.5	351	13.9
hienuki	1,560	14.1	118.3	12.6	1,186	10.7
Nangun-	363	7.0	46.6	22.1	362	7.0
takedate	6,607	40.5	146.0	19.5	880	5.4
Kokuso[a]	638	24.5	24.2	19.0	94	3.6
	366	17.3	19.2	17.1	17	0.8
Tokachi-	591	13.4	42.0	20.3	215	4.9
nagaha	2,922	56.3	49.1	16.1	167	3.2

[a]Kokuso is an extremely early ripening variety.

10. STUDY ON THE SOYBEAN-CYST NEMATODE IN MANCHURIA

A paper by K. Nakata and H. Asuyama (1938) discusses the soybean-cyst nematode in Manchuria. Drs. Nakata and Asuyama were requested by the Government of Manchukuo to make a general survey of the diseases of crops in Manchuria, and their report was made in "Survey of the principal diseases of crops in Manchuria", Report No. 32 from Bur. of Industry, 166 pp., 1938, (in Japanese). A part of this article (pages 62-63) was translated as follows:

> a. Distribution and Injury: The soybean-cyst nematode was found at Khu-lan (Pin-kiang hsiu), Tsi-tsi-har (Helung-kiang hsiu), Tao-nan, Khi-shu-lien (Kih-rin-hsiu), where the damage of some varieties of the soybean were so serious that they entirely failed to grow and died early. This disease does not seem to be spread widely at this time except in the above-mentioned district.
>
> b. Environment for the Outbreak of the Disease: It is said that nematode invasion to living plants is more severe in soil deficient in organic matter, and the damage of plants is particularly severe in infertile soil. It seems that this disease is severe in areas where there is much rainfall and slight in dry land, and this is thought to be a reason why the disease is widely spread in the Tsi-tsi-har and Tao-nan districts. It is very likely that this disease is most common in the south-western part of Manchuria just as it is most common in the southern part of Hokkaido, Japan.
>
> c. Varieties: The damage of the soybean plant by this nematode is, to a great extent, connected with the resistance of the variety concerned. In Tsi-tsi-har district, variety "Kung No. 557" is resistant to this nematode, varieties "Kung No. 555" and "Kung No. 556" are most susceptible and "Huang-pao-chu" is intermediate in susceptibility. In Tao-nan, variety "Huang-pao-chu" is highly susceptible, and every variety which was bred with the variety "Huang-pao-chu" was found susceptible.

Literature Cited

1. FRANKLIN, M. T. 1940. On the specific status of the so-called biological strains of Heterodera schachtii Schmidt. Jour. Helminth. 18: 193-208.
2. FUJITA, K., and O. MIURA. 1934. On the parasitism of Heterodera schachtii Schmidt on beans. Trans. Sapporo Nat. Hist. Soc. 13: 359-364.

3. HORI, S. 1915. Phytopathological Notes. 5. Sick soil of soybean caused by a nematode. (in Japanese). Jour. Pl. Protect. 2: 927-930.
4. ICHINOHE, M. 1952. On the soybean nematode, Heterodera glycines n. sp., from Japan. Magazine of Appl. Zool. 17: 1-4.
5. ICHINOHE, M. 1953. On the parasitism of the soybean nematode, Heterodera glycines. Hokkaido Nat'l. Agr. Exp. Sta. Res. Bul. 64: 113-124.
6. ICHINOHE, M. 1955. A study on the population of the soybean nematodes (Heterodera glycines). 1. An observation on the relation between the crop damage and the female infestation. (in Japanese). Hokkaido Nat'l. Agr. Exp. Sta. Res. Bul. 68: 67-70.
7. ICHINOHE, M. 1955. Studies on the morphology and ecology of the soybean nematode, Heterodera glycines, in Japan. (in Japanese) Hokkaido Nat'l Agr. Exp. Station Report 48: 64 pp.
8. ICHINOHE, M. 1955. Survey on the "yellow dwarf" disease of soybean plants caused by Heterodera glycines occurring in the peat soil in Hokkaido. (in Japanese) Jap. Jour. Ecol. 5: 23-26.
9. ICHINOHE, M. 1956. Studies on the resistance of soybean plants to the nematode, Heterodera glycines. 1. Varieties, "Daiichi-hienuki" and "Nangun-takedate". (in Japanese) Hokkaido Nat'l Agr. Exp. Station Res. Bul. 71: 67-79.
10. ISHIKAWA, T. 1916. Principal insect pests and diseases of plants occurring during the fourth year of Taisho. 11. Occurrence of "Moon night" and wilt disease of soybean. (in Japanese). Jour. Pl. Protect. 3: 197.
11. ITO, S. 1921. Studies on "Yellow dwarf" disease of soybean. (in Japanese). Hokkaido Agr. Exp. Sta. Report 11: 47-59.
12. KATSUFUJI, K. 1919. "Yellow dwarf" a new nematode disease of soybean. Ann. Phytopath. Soc. Jap. 1: 1-5.
13. NAKATA, K., and H. ASUYAMA. 1938. Survey of the principal disease of crops in Manchuria (in Japanese). Bur. of Indust. Rep. 32: 166 pp.
14. TANAKA, T. 1921. On soybean nematode. (in Japanese) Jour. Pl. Protect. 8: 551-553.

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